Further Investigation into VHF Radio Wave Propagation Loss over Long Forest Channel

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Abstract– This paper presents the experimental study on the radio wave propagation loss through long tropical forest environments at Very High Frequency, VHF (92.1MHz as a case study). The method of least square was employed to fit the experimental measured data. The measured data were then compared with some existing analytical and empirical radio propagation loss models, namely: Free Space Attenuation (FSA), Ground Reflection (GR) and Canopy-Ground Reflection (CGR), CGR plus foliage (ITU-R model) and CGR plus foliage (Weissberger model). CGR model provides the best fit for the propagation loss at VHF (92.1MHz) over long tropical forest. CGR model has minimum Normalized root-mean-square deviation, NRMSD = 0.106%. NRMSD between the measured data are the other existing models are: FSA~0.828%, GR~0.122%, CGR plus foliage (ITU-R)~0.410% and CGR plus foliage (Weissberger)~0.668%. The results obtained therefore shown that the radio wave propagation loss in the channel of consideration is due to tree-Canopy and Ground Reflections (CGR) rather than the foliage induced effect.

Keywords: Experimental measurement, Propagation loss, Very High Frequency, Long tropical forest

I. INTRODUCTION

There are reports that the appearance of the forest (foliage and vegetation) medium in the part of the communication links can significantly affect the quality of the signal received because the forest components such as the randomly distributed leaves, Twigs, branches, tree's groove, tree- canopy and tree's trunk, air and ground layers cause reflection, refraction, diffraction, absorption and hence scatter the propagating radio waves which lead to path loss, and attenuation of the waves [1] – [13]. This will severely constrain the performance of the communication system and therefore has been of interest to researchers for many years. Several researches, theoretical and experimental works have been carried out and reported on the modeling of radio propagation loss through the forested channels at HF, VHF, UHF and microwaves bands [1] – [11]. The significance of radio wave propagation loss prediction in the communication channels can not be over-emphasizing in planning, budgeting and design of communication systems. It has been identified that the major adverse effect of radio wave propagation loss when not checked is the complete breakdown of communication systems [1], [9], [10], [13], [14].

Despite numerous researches on the propagation loss modeling at HF, VHF and UHF, most of the existing models in the forested channels are theoretically and empirically based; they are based on the experiment carried out in the laboratories using dissipative slab materials and water in bottles as representations of ground and trees in the forest environments or a periodic dielectric rod array and an array of water-filled straws in the Laboratory as a simplified, scaled model of a typical forest [2] – [8]. They are not based on physical measurements in the real physical forest environments. Consequently, the models may not have high prediction accuracy, and need to be re-investigated. Also, to the best of our knowledge based on available information in the open literatures, there are no reported VHF radio wave propagation loss models available for very long depth forested channels [2] – [8].

In this paper, some existing radio wave propagation loss models for the forested environments are briefly reviewed. As a continuation of the research progress on radio propagation characteristics through forested channels, the experimental measurements carried out on the radio wave propagation loss at VHF (92.1MHz as a case study) through long (~64km) forested communication channels are reported. The experimental measurement results obtained are compared with some existing propagation loss models: Free Space Attenuation (FSA), Ground Reflection (GR) and Canopy Ground Reflection (CGR) models, and integration of foliage-induced effect and reflection effect models: CGR plus ITU-R or SUM(CGR, ITU-R) and CGR plus Weissberger or SUM(CGR, Weissberger). Using the method of least square fit to the experimental measured data, CGR model gives the best fit for the radio wave propagation loss at VHF (92.1MHz) through long tropical forested channel. This paper is organized as follows: Section I gives the introduction of the behaviour of the propagation of radio wave through forest channels. Section II briefly review some related work on the

radio wave propagation in the forest. Section III explains the experimental method used to carry out the study. Section IV explains the results obtained and gives the implications. The last section V concludes the paper and followed by references and author biography.

II. REVIEW OF SOME PREVIOUS WORKS ON RADIO PROPAGATION LOSS IN THE FOREST ENVIRONMENTS

Gurung and Zhao, 2011 and McLarnon, 1997 as in [1], [12], gave some theoretical insight into the nature of radio wave propagation in VHF and Micro wave bands. The free space (Line of Sight, LOS) radio wave propagation loss can be calculated using Friis transmission formula given by [1], [12]:

$$P_R = P_T + G_T + G_R - 32.4 - 20\log_{10} f - 20\log_{10} d - L_T - L_R \quad \text{dBm,} \quad (1)$$

Where, f = resonant frequency in MHz, d = distance covered by the radio waves in km, P_T = transmitter power output in dBm, P_R = received power, G_T and G_R = transmit and receive antennas gain in dBi respectively, L_T = Transmission line loss between transmitter and transmit antenna in dB, L_R = transmission line loss between receiver input and receive antenna in dB. The free space attenuation (FSA), A is then determined from the expression given as:

$$A = 10\log_{10}\left(\frac{P_R}{P_T}\right), \quad \text{dB} \quad (2)$$

Also, Alade, 2012 [15] presented the standardized free space attenuation, FSA (or Free Space Loss, FSL) of radio wave propagation in free space (LOS) as:

$$A = 147.5571 - 20\log_{10} f - 20\log_{10} d \quad \text{dB,} \quad (3)$$

Where, f = resonant frequency in Hz, d = distance covered by the radio waves in meters (m).

On the radio wave propagation characteristics in the forest environments (non LOS), some fairly reliable analytical and empirical propagation loss models available are based on the earlier laboratory experimental results, and not really on physical measurements in the real physical forest environments. Some of well known empirical radio wave propagation loss models for forest environment reviewed by previous authors are listed as follows [3], [4], [6], [8]: The Weissberger's modified exponential decay model which is applicable, where a ray path is blocked by dense, dry, in-leaf trees found in temperate climates and where the propagation is likely to occur through a groove of trees rather than the canopy top is given as:

$$L_W = \begin{cases} 1.33 \times f^{0.284} d_f^{0.588}, 14\text{m} > d_f \leq 400m. \\ 0.45 \times f^{0.284} d_f, \ 0\text{m} \leq d_f < 14m. \end{cases} \quad \text{dB , (4)}$$

Where, f is the resonant frequency in GHz and d_f is the forest depth in meters (m). The ITU recommendation (ITU-R) model which was developed from measurement carried out mainly at UHF band, and was proposed for the cases where either the transmitting or receiving antenna is near to a small ($d_f < 400$m) groove of trees so that the majority of the signal propagates through the trees. It is given as:

$$L_{ITU-R} = 0.2 \times f^{0.3} d_f^{0.6} \quad \text{dB,} \quad (5)$$

Where, f is a resonant frequency in MHz and d_f is forest depth (distance) in meter.

As extension of research on modeling of radio wave propagation in the forest environments, a new method to model ground short-range propagation loss in forested areas with tree-canopy effect at the VHF and UHF bands using integration of the existing empirical foliage loss model (Weissberger and ITU-R or COST 235) and ray tracing model (as shown in the figure 1) to include the loss effect from ground and tree canopy reflections was developed by [6].
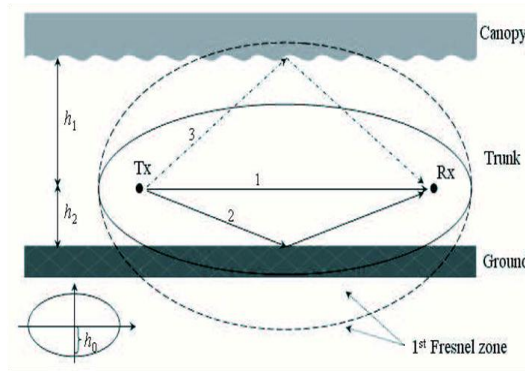

Figure 1: Showing the Ray tracing model of the direct (1), ground-reflected (2), and tree-canopy reflected (3), waves [6].

The ray tracing model of the path loss $L_{1\text{-reflected}}$ due to the ground – reflection only is given by:

$$L_{1-reflected} \cong FSL - 20\log_{10}(\Delta\phi) \quad \text{dB, (6)}$$

Where the tree-canopy reflection is present, the ray tracing model of the path loss $L_{2\text{-reflected}}$ due to the tree canopy reflection only (or both reflections) is given by:

$$L_{2-reflected} \cong FSL - 20\log_{10}(1 + 2\Delta\phi_1\Delta\phi_2) \quad \text{dB, (7)}$$

Where, $\Delta\phi$ is the phase different between the direct and reflected rays, and it is given by:

$$\Delta\phi = \frac{4\pi h_T h_R}{\lambda d_f}, \quad (8)$$

Where, h_T and h_R are the transmitting and receiving antenna heights over the ground in meters respectively. It is assumed that d_f is larger then h_T and h_R,. $\Delta\phi_1$ and $\Delta\phi_2$ are the phase differences between the direct and ground-reflected rays and the direct and tree-canopy reflected rays respectively. For $\Delta\phi_1$, $h_T = h_R = h_2$; and for $\Delta\phi_2$, $h_T = h_R = h_1$ (see figure 1).

By incorporating the foliage-induced excess loss for the radio-wave propagation through the forest medium, the following models were obtained [6]: The path loss (PL) model due to the tree-canopy reflections (or tree-canopy and ground reflections) is given by:

$$PL_{forest} \cong L_{foliage} + L_{2-reflected} \quad \text{dB, (9)}$$

The path loss (PL) model due to the ground reflection only is given by:

$$PL_{forest} \cong L_{foliage} + L_{1-reflected} \quad \text{dB, (10)}$$

Where, $L_{foliage}$ can be L_W, or L_{ITU-R}, etc.

III. MEASUREMENTS CAMPAING AND COMPUTATIONS

The tropical forest where the experiment took place is located between Ogbomoso (LAT 8° 29'N, LONG 4° 29'E) and Oyo (LAT 7° 50'N, LONG 3° 56'E), Nigeria. The forest can be classified as medium dense to dense vegetations with mixed different types of plants. Figure 2a, b shows some parts of the forest. The forest consists of types of plants like Thick, Mahogany, Iroko, Mango and palm trees etc. Dense canopies are formed by the leaves of the trees. The average thickness (trunk diameter) and height of the trees range between 0.76m to 2.56m and 5.07m to 15.3m respectively. The spacing between the trees is irregular and ranges between 3m to 7m. The forest ground is covered with scrubs. The 92.1MHz, 3.5kW transmitter is employed in the experiment and located within the forest environment of interest. It consists of the transmitting antenna of 130m high, and the actual power radiated from the antenna after transmitter and cable losses are deducted is 2.5kW. The

experimental measurement set up is as shown in the figure 2c. The experimental measurements were carried out by moving a low gain standard receiving dipole antenna (~0.5m from the ground surface) well matched to the receiver system (GSP810-Spectrum Analyser) set up inside a vehicle to measure the received signal power in dBm at 1km interval from the transmitting antenna up to 64km along the forest channel. The computations and statistical analyses were achieved with aid of Microsoftexcel2007. The graphical analyses were done with the aid of Matlab2007R.

IV. RESULTS AND DISCUSSION

In this paper, the radio wave propagation characteristics through long forested channel at VHF (92.1MHz as a case study) were investigated experimentally. The measurements were carried out in the months of October, November and December, 2011, under no wind, and no rain weather conditions with daily average ambient temperature ranges between 29°C and 34°C. Having measured the signal power received at every 1km interval to cover 64km through the desired forested channel, the measured attenuation in dB was deduced using Equation 2. Figure 3 is the plot of attenuation versus forest distance for the measurements, FSA, GR, and CGR models. Figure 4 is the plot of attenuation versus forest distance for the measurements, SUM(CGR, ITU-R) and SUM(CGR, Weissberger) models. All the existing analytical and empirical models were compared with the measurements. For all the cases, the attenuation decreases with distances, d_f along the forest channel.

The table 1 shows the statistical data for all the data plotted in Figures 3 and 4. The CGR model provides the best fit to the experimental measurements data, and closely followed by GR model. The FSA model of radio wave propagation loss, since it is based on free space communication links (LOS), does not include the additional loss on the propagation components such as direct wave and reflected, refracted, diffracted waves etc through the complex communication channels like forest, and therefore, it does not have ability to model forest links accurately. Also, based on the results obtained, SUM(CGR, ITU-R) and SUM(CGR, Weissberger) models which incorporated the foliage-induced excess loss for the radio-wave propagation through the forest medium have failed to adequately handle the radio waves propagation loss at VHF band through long forest depth.
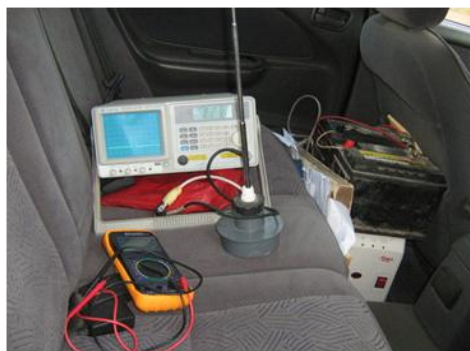
V. CONCLUSION

This paper presents the experimental modeling of VHF (92.1MHz) radio wave propagation loss through the long tropical forest depth channel. The results obtained shown that the radio wave propagation loss in the channel of consideration is due to the tree-canopy and ground reflections rather than the reflections from the groove and trunk of trees. If there is any additional propagation loss, it is not due to foliage induced effect. Therefore, the appropriate propagation loss model is tree-canopy and Ground Reflections (CGR) model.

(a)

(b)   (c)

Figure 2: Showing photographs of (a) part of the forest, (b) equipments for the measurements displayed
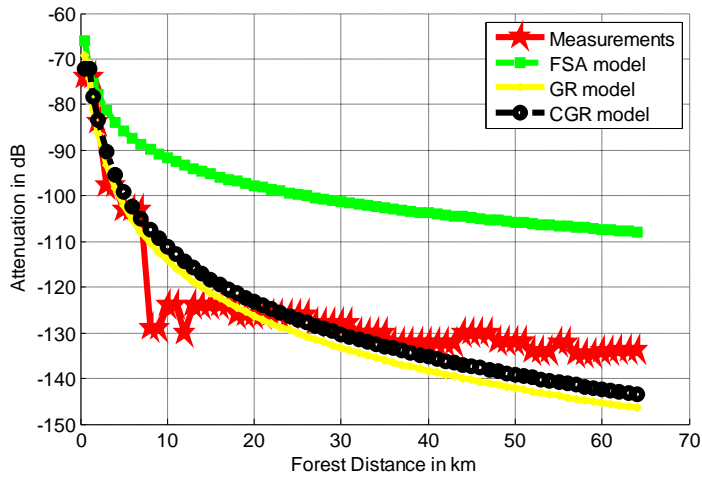and (c) the measurement set-up.

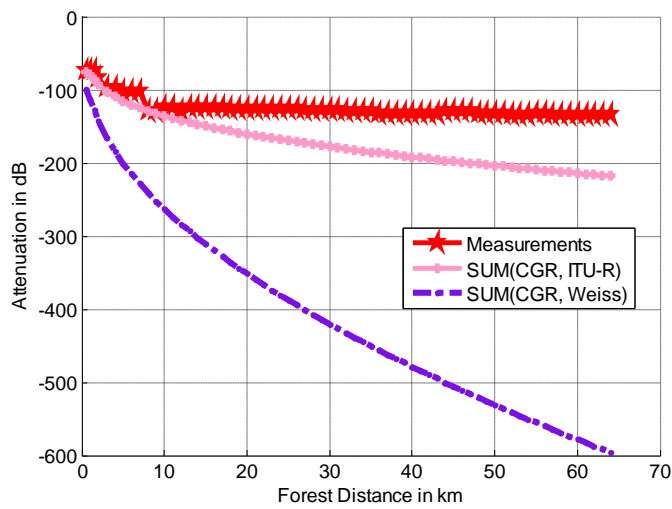Figure 3: Showing the measured propagation loss compared with the FSA, GR and CGR models.

Figure 4: Showing the measured propagation loss compared with the SUM(CGR, ITU-R) and SUM(CGR,Weiss)models.

TABLE I.

STATISTICAL DATA COMPARING THE MEASUREMENTS WITH ANALYTICAL AND EMPIRICAL MODELS

Models	Correlation Coefficient	Chi-Square Test	Normalized Root-Mean-Square Deviation
FSA	0.900932	$\sim 10^{-43}$	0.828%
GR	0.900932	0.999707	0.122%
CGR	0.900932	0.999998	0.106%
SUM(CGR, ITU-R)	0.843118	$\sim 10^{-257}$	0.410%
SUM(CGR, Weiss)	0.800545	0	0.668%

REFERENCES

[1] Gurung, S., and Zhao, J., ''Attenuation of microwave Signal and its impact on communication system'', Retrieved on September 14, 2011 from http: //www.sanjayagurung.com, 2011.
[2] Tamir, T., ''On radio-wave propagation in forest environments'', IEEE Transactions on Antennas and Propagation, Vol. 15, Issue 6, pp. 806 – 817, 1967.
[3] Meng, Y. S., Lee, Y. H., and Ng, B. C., ''Study of propagation loss prediction in forest environment'', Progress In Electromagnetics Research B, Vol. 17, pp. 117–133, 2009.
[4] Meng, Y. S., Lee, Y. H., and Ng, B. C., ''Empirical near ground Path Loss modeling in a forest at VHF and UHF bands'', IEEE Transactions on Antennas and Propagation, Vol. 57, No. 5, pp. 1461 – 1468, May 2009.
[5] Prasad, M. V. S. N., Rama, R. T., Iqbal A., and Paul, K. M., ''Investigation of VHF signals in bands I and II in southern India and model comparisons'', Indian Journal of Radio and Space Physics, Vol. 35, pp.198 – 205, June 2006.
[6] Meng, Y. S., Lee, Y. H., and Ng, B. C, ''Pathloss modelling for near-ground VHF radio-wave propagation through forests with tree-canopy reflection effect'', Progress In Electromagnetics Research M, Vol. 12, pp. 131–141, 2010.
[7] Blaunstein, N., Censor, D., Katz, D., Freedman, A., and Matityahu, I., ''Radio propagation in rural residential areas with vegetation'', Progress In Electromagnetics Research, PIER 40, pp. 131–153, 2003.
[8] Yang Li., and Hao Ling., ''Investigation of wave propagation in a dielectric rod array: Toward the understanding of HF/VHF propagation in a forest'', IEEE Transactions on Antennas and Propagation, Vol. 58, Issue 12, pp 4025 – 4032, doi:10.1109/TAP.2010.2078456, September 2010.
[9] Lee., ''Mobile Communications Engineering: Theory and Applications'', McGraw-Hill, USA, 1998.
[10] Wesolowski, K., *''Mobile Communication System''*, ISBN: 0471 498378, John Wiley and Sons Ltd., New York, 2002.
[11] Durgin, D., Rappaport, S. T., and Xu, H., ''Measurements and models for radio path loss and penetration loss in and around homes and trees at 5.85GHz'', IEEE Transactions on Communications, Vol. 46, No. 11, 1998, pp. 1484 – 1496, November 1998.
[12] McLarnon, B., ''VHF/UHF/Microwave Radio Propagation: A Primer for Digital Experimenters'', *A workshop given at the 1997 TAPR/ARRL Digitial Communications Conference, http/www.tapr.org/ve3jf.dcc97.html,* 1997.
[13] Seybold, J. S., ''*Introduction to RF propagation*'', ISBN: 0471655961, New Jersey, John Wiley and Sons Inc., pp. 111 – 133, 2005.
[14] Bostian, C. W., Brandon, W. T., Chan, V. W. S., Jennings, R. D., and Pelton, J. N., ''New markets and policy considerations on Radio Waves Propagation and Attenuation'', Chapter 4, *Published by WTEC Hyper-Libraria*, 1995.
[15] Alade, M. O., ''Standardization of attenuation formula for radio waves propagation through free space (LOS) communication links,'' Science Journal of Physics, Vol. 2012, http://www.sipub.org/sjp.html, 2012.

Alade Olusope Michael was born in Nigeria, in 1970. He received the B.Sc degree in Physics and M.Sc degree in Applied Physics from University of Jos, Nigeria in 1994 and 1998 respectively. Also, he received the Ph.D in Applied Physics from Ladoke Akintola University of Technology Ogbomoso, Nigeria in 2005. His research interests include design and analysis of electronic communication devices; and radio wave propagations. From 2010 to till date he is working as Associate Professor of Communication Physics.